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Application of a modified irrigation method using compensated radiation integral, substrate moisture content, and electrical conductivity for soilless cultures of paprika

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ABSTRACT

Irrigation strategy has a direct influence on the productivity and the production cost of soilless cultures of paprika, and thus more efficient irrigation methods are required. The objective of this study was to compare water use efficiency and crop productivity between a conventional irrigation method and a modified irrigation method using a precise irrigation control system. Accumulated radiation was used as an irrigation index for the conventional method as a control, whereas the compensated value of accumulated radiation as well as the substrate moisture content and electrical conductivity was used as irrigation indices for the modified one. Plant growth and water use efficiency were compared between both irrigation systems. The experiment was performed in a commercial farm cultivating paprika in Hwasung, Korea. For the modified method, the substrate moisture content was well-controlled in the range of 69–85% and showed a narrow fluctuation compared to the control. Additionally, the substrate electrical conductivity was maintained within 2.4–4.6 dS m^{-1} during the growth period, whereas the substrate electrical conductivity increased up to 7.9 dS m^{-1} for the control. Water consumption and water-use efficiency of the shoots and fruits were 6.6% and 3.7% higher, respectively, with the modified method compared to the control. Overall plant growth was better with the modified method. Based on these results, it could be concluded that the modified irrigation method improved the productivity of paprika in soilless cultures.

1. Introduction

Because paprika plants show a high sensitivity to the moisture level of the root zone among Solanaceae crops (Sezen et al., 2006), an optimal irrigation strategy should be required to increase fruit production, as well as to save money on production costs (De Pascale et al., 2011; Karam et al., 2009), particularly in large-scale greenhouses. In fact, water management is one of the important aspects of paprika cultivation, but it is not easy to manage water efficiently due to various environmental conditions and changes according to region. Until now, most irrigation strategies have been managed based on the grower's experience and conventional cultivation manuals. To maintain optimal water conditions in the substrate, the development of systematic irrigation systems with real-time monitoring of environmental factors and irrigation controls considering plant water uptake and root-zone environments are needed.

Many studies of algorithms for irrigation control have been focused on active water management considering crop conditions to solve problems with conventional irrigation methods. There have been several attempts to apply water transport properties according to substrate type and irrigation method for irrigation management (Bougoul and Boulard, 2006; Kong et al., 2012). Liu et al. (2012) and Zotarelli et al. (2011) reported irrigation criteria with moisture content (MC) measured with moisture sensors. In addition, Bryla et al. (2010) calculated the amount of water that should be supplied by measuring plants and substrate weights. Bonachela et al. (2006) developed an irrigation strategy using accumulated weather data.

However, the crop response to water uptake was not quantified in these studies of irrigation methods. Shin et al. (2014) quantified the transpiration amount while monitoring crop response to water uptake and used it as an indicator for irrigation control. They also showed that the transpiration rate did not proportionally increase with an increase in light intensity, especially in high-

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light conditions and used a compensated value of the accumulated radiation conventionally used in irrigation control. Additionally, as limited root-zone conditions induce drought stress in paprika (Ben-Gal et al., 2008; Kurunc et al., 2011 Morales-Garcia et al., 2011), more advanced irrigation methods based on drainage rate (Kim et al., 2011), substrate salinity and MC (Havrda et al., 1989; Liu et al., 2012) were proposed. However, a complex irrigation control considering radiation and root-zone environments has not been attempted yet.

It was assumed that fruit yields could be improved and production costs could be saved in commercial farms using a precise irrigation system with systematic irrigation strategies considering compensated radiation and root-zone conditions, such as substrate electrical conductivity (EC), MC, and drainage rate. The objectives of this study were to verify the performance of a modified irrigation method (MIM) using those four factors and to compare the plant growth and water usage between MIM and a conventional irrigation method (CIM) at a large-scale commercial farm.

2. Materials and methods

2.1. Experimental conditions

The experiment was conducted in a venlo-type greenhouse at the commercial farm of 'Hwasung 21' (Hwasung, Korea, lat. 37.0°N, long. 126.8°E) (Fig. 1). Paprika plants (*capsicum annuum* 'Veyron') were sown on March 15, 2012 and transplanted to rockwool slabs [(120 (*L*) × 12 (*W*) × 7 cm (*H*), Grotop, Grodan, Roermond, Netherlands] on June 8, 2012 [85 days after sowing (DAS)]. Irrigation treatments were applied after the transplant. The plants were arranged in two rows for each lane, and 90 plants in each row were planted with a planting density of 3.6 plants m^{-2}. A total of 360 plants (180 plants for each treatment) located in the middle of the greenhouse were used for the experiment. The total 5 plants sampled at every 18 plants alternately in the two rows were used for measuring the plant growth each treatment. The ranges of EC and pH of the supplied nutrient solutions were 2.4–2.8 dS m^{-1} and 5.5–6.0, respectively, during the growth period. The same nutrient solutions were supplied to both the control plants and the irrigation treated plants. The nutrient solution was not reused after irrigation. The temperature and relative humidity inside the greenhouse were controlled within the range of 15–29 °C and 50–80%, respectively, during the growth period. The plants were pruned to form three main stems. The axillary shoots of the flowers and leaves were pruned, and two fruits remained at every 2 nodes according to the management manual. (Hellemans, 2006).

Fig. 1. An experimental view of the paprika cultivation at a commerecial greenhouse (Hwasung 21, Hwasung, Korea).

2.2. Measurements

The number of irrigation events, supplied water amounts, drainage amounts, drainage rate, substrate MC and EC, and transpiration were continuously measured and collected using the irrigation monitoring and control system (Shin et al., 2014). The solar radiation, temperature, and relative humidity were measured every 5 sec by using a pyranometer (SP-110-L10, Apogee Instruments, Logan, Utah, USA), a thermometer (CS220 E-type thermocouple, Campbell Scientific, USA), and a hygrometer (PCMini70, Michell Instruments, Ely, UK), respectively. The leaf area index (LAI) was calculated by measuring the length and width of the leaves every week during the growth period (Ta et al., 2012). The fruits were harvested at the beginning of coloring. Fallen fruits were not counted. The supplied water amount and water use efficiency were compared. The transpiration amount was obtained by calculating the weight change in the substrate with the 8 plants measured every 10 min by two load cells at each treatment (JSB-50, CAS, Yangju, Korea). The irrigation and drainage amounts were continuously measured by using the load cells. The substrate MC and EC were measured by using a FDR sensor (WT1000B Frequency Domain Reflectometry, Mi-Rae Sensor, Seoul, Kor.) installed between two plants in the slab. Three FDR sensors were set up at each treatment by 30-plant interval. The average data of the MC and EC from the three FDR sensors in each treatment were collected every 5 s. The MC and EC were continuously monitored during the experimental period. Plant height, the number of nodes, leaves, and fruits were measured every week. The data between treatments were compared at the end of cultivation by the least significant difference (LSD) test at $p = 0.05$ with the statistical analysis program SAS 9.3 (SAS Institute, Cary, NC, USA). From the collected data, water use efficiency (fresh weight/transpiration amount) was calculated and compared. The sugar contents of three fruits from per treatment were measured after harvest with a saccharimeter (RHB-32, Will Science, Seoul, Korea) to compare fruit quality. Graphs were expressed with Sigma Plot Ver. 13 (Systat Software, San Jose, CA, USA).

2.3. Control of irrigation intervals and amounts

To verify the performance of MIM compared to CIM, the irrigation intervals and amounts were controlled as described in Table 1. For CIM, 110 mL of water were supplied to each plant whenever the accumulated radiation reached a certain level and the compensated value of accumulated radiation for MIM reached 100 J m^{-2}. The compensated value of accumulated radiation (RAD) was calculated from the accumulated radiation (RAD) and applied to MIM (Eq. (1)). Because the transpiration does not increase in proportion to light intensity in the regions of high light intensity, RAD should be compensated (Shin et al., 2014).

$$\mathrm{RAD}' = \frac{a}{1+\exp^{\left(\frac{x_0-\mathrm{RAD}}{b}\right)}} - c \tag{1}$$

where, the coefficients x_0, a, b, and c were 81.61, 1.41, 40.91, and 28.10, respectively.

The available irrigation time was from sunrise to 15:30 for both CIM and MIM. Following the irrigation procedures used in previous research (Shin and Son, 2015), substrates MC (below 70%) and EC (above 4.5 dS m^{-1}) were added to the radiation-based irrigation control in MIM. Once irrigation started, it could stop when substrate MC reached 85% or the substrate EC decreased below